Flyback Converter Using Contant-Ton
(26 Dec 2003)

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1 Introduction

The purpose of this write-up is to describe the feasibility of using constant-Ton control scheme (of Little John) for the control of flyback dc-dc converter.

There is an internal voltage ramp waveform (emulator) that emulates the external transformer current. In flyback converter, the transformer primary current is present during Ton (when switch is on) whereas secondary current is present during Toff.

The SKIP-mode that is used in Little John is not applicable in the flyback converter since during light-load, flyaback converter will enter into discontinuous conduction mode. In such case, the emulator will only need to provide a Ton pulse that limit the transformer peak current (in Little John, the inductor current). Hence the discharge of the internal voltage ramp waveform can be as fast as possible, taking into consideration such as expected load transient (from light load to heavy load) and minimum duty cycle expected in various condition (battery voltage, transformer turn ratio and load variation).

The circuit control scheme is as shown in next page:

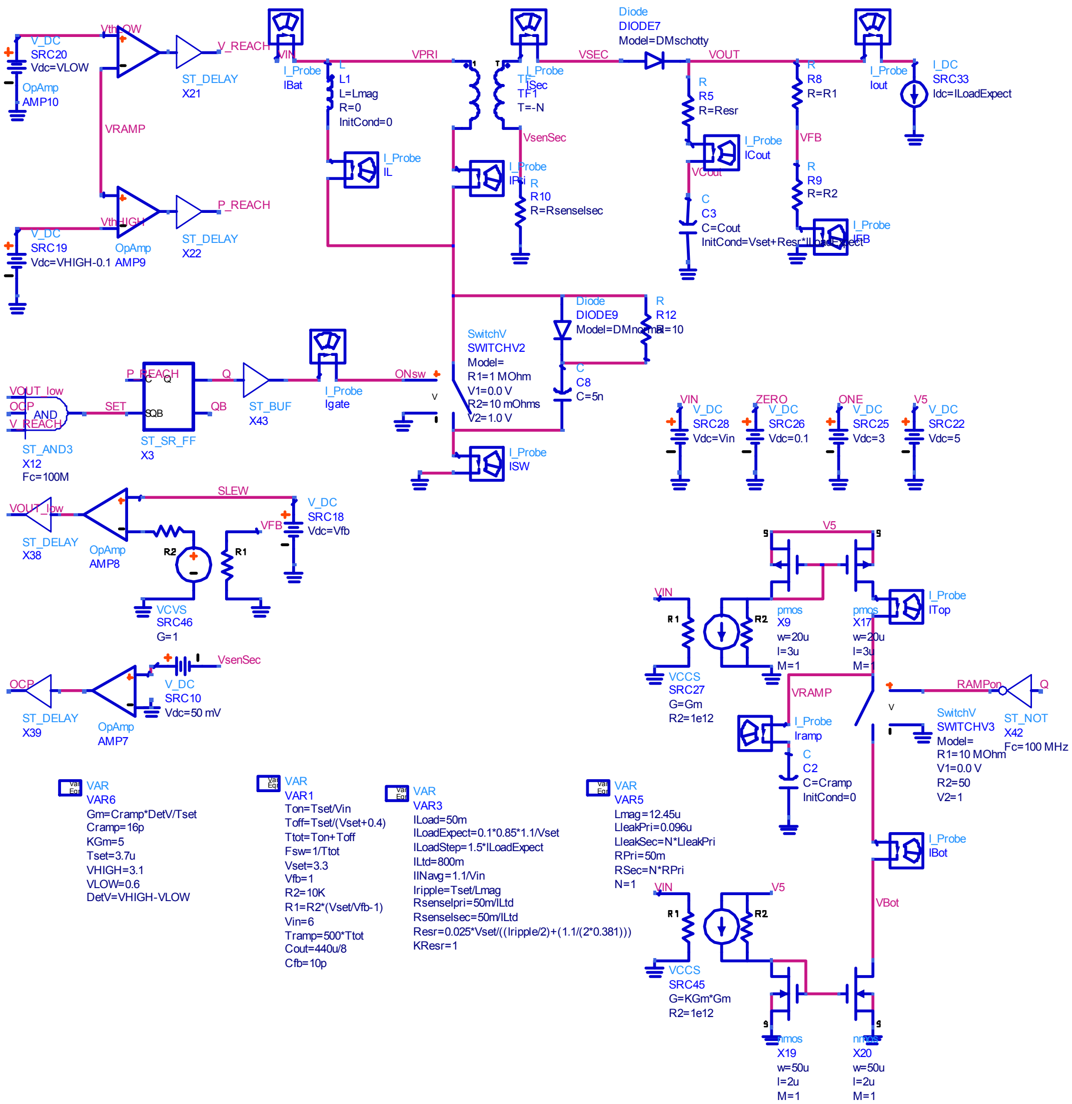
VRAMP is the emulator waveform. Two comparators are used to detect the peak and valley of the waveform.

A constant-Ton pulse is fired whenever the three conditions are met:

1. Valley of VRAMP is reached.
2. No over-current condition present.
3. VOUT is lower than the SLEW.

When the constant-Ton is fired, energy is transferred into the transformer. At the end of the pulse, the power switch is off (Toff) and energy is transferred from the transformer into the output capacitor.

Since the over-current protection scheme is valley detection type, the sense resistor is placed in secondary. Firing of constant-Ton pulse is allowed only when the secondary current have drop below a threshold (set by sense resistor). In such way, the over-current protection is realized. The inherent disadvantage is that the accuracy of the transformer turn ratio will also affect setting of the over-current limit.

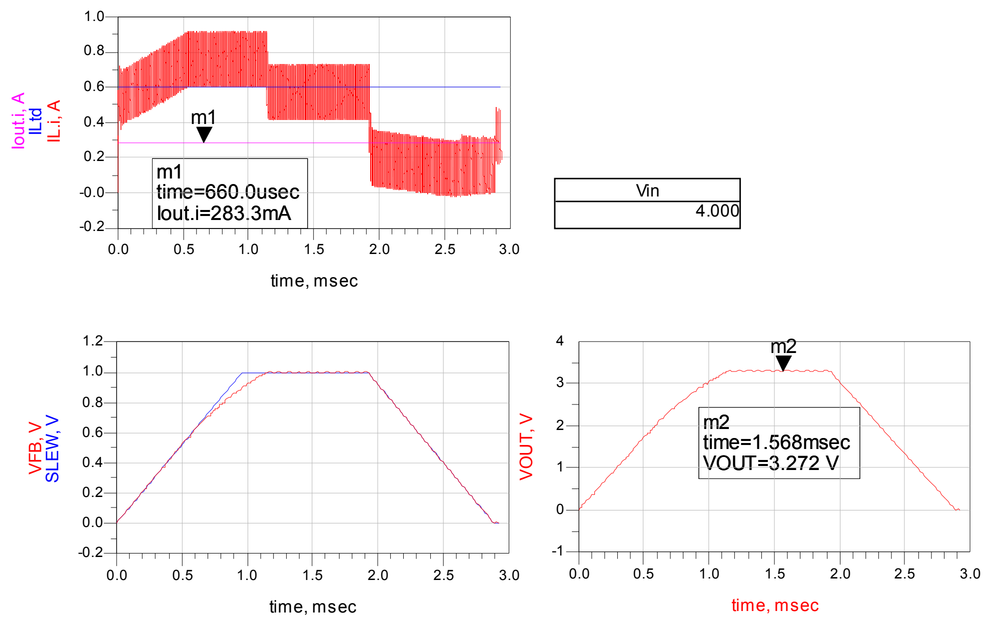

VthLOW
V_REACH
V_DC
SRC20
Vdc=VLOW
OpAmp
AMP10
ST_DELAY
X21
VIN
I_Probe
IBat
L
L1
L=Lmag
R=0
InitCond=0
VPRI
I_Probe
IL
TF
TF1
T=-N
I_Probe
ISec
VSenSec
I_Probe
IPri
R
R10
R=Rsenselsec
VSEC
Diode
DIODE7
Model=DMschotty
VOUT
R
R5
R=Resr
I_Probe
ICout
VCout
C
C3
C=Cout
InitCond=Vset+Resr*ILoadExpect
R
R8
R=R1
VFB
R
R9
R=R2
I_Probe
IFB
I_Probe
Iout
I_DC
SRC33
Idc=ILoadExpect
VRAMP
VthHIGH
P_REACH
V_DC
SRC19
Vdc=VHIGH-0.1
OpAmp
AMP9
ST_DELAY
X22
Diode
DIODE9
Model=DMnormal
R
R12
R=10
SwitchV
SWITCHV2
Model=
R1=1 MOhm
V1=0.0 V
R2=10 mOhms
V2=1.0 V
C
C8
C=5n
P_REACH
Q
QB
SET
VOUT_low
OCP
V_REACH
AND
ST_AND3
X12
Fc=100M
ST_SR_FF
X3
ST_BUF
X43
I_Probe
Igate
ONsw
I_Probe
ISW
VIN
V_DC
SRC28
Vdc=Vin
ZERO
V_DC
SRC26
Vdc=0.1
ONE
V_DC
SRC25
Vdc=3
V5
V_DC
SRC22
Vdc=5
VOUT_low
ST_DELAY
X38
OpAmp
AMP8
SLEW
V_DC
SRC18
Vdc=Vfb
VFB
R2
R1
VCVS
SRC46
G=1
OCP
ST_DELAY
X39
OpAmp
AMP7
V_DC
SRC10
Vdc=50 mV
VsenSec
V5
VIN
R1
R2
pmos
X9
w=20u
l=3u
M=1
pmos
X17
w=20u
l=3u
M=1
I_Probe
ITop
VCCS
SRC27
G=Gm
R2=1e12
VRAMP
I_Probe
Iramp
C
C2
C=Cramp
InitCond=0
RAMPon
Q
SwitchV
SWITCHV3
Model=
R1=10 MOhm
V1=0.0 V
R2=50
V2=1
ST_NOT
X42
Fc=100 MHz
I_Probe
IBot
VIN
V5
R1
R2
VBot
VCCS
SRC45
G=KGm*Gm
R2=1e12
nmos
X19
w=50u
l=2u
M=1
nmos
X20
w=50u
l=2u
M=1
VAR
VAR6
Gm=Cramp*DetV/Tset
Cramp=16p
KGm=5
Tset=3.7u
VHIGH=3.1
VLOW=0.6
DetV=VHIGH-VLOW
VAR
VAR1
Ton=Tset/Vin
Toff=Tset/(Vset+0.4)
Ttot=Ton+Toff
Fsw=1/Ttot
Vset=3.3
Vfb=1
R2=10K
R1=R2*(Vset/Vfb-1)
Vin=6
Tramp=500*Ttot
Cout=440u/8
Cfb=10p
VAR
VAR3
ILoad=50m
ILoadExpect=0.1*0.85*1.1/Vset
ILoadStep=1.5*ILoadExpect
ILtd=800m
IINavg=1.1/Vin
Iripple=Tset/Lmag
Rsenselpri=50m/ILtd
Rsenselsec=50m/ILtd
Resr=0.025*Vset/((Iripple/2)+(1.1/(2*0.381)))
KResr=1
VAR
VAR5
Lmag=12.45u
LleakPri=0.096u
LleakSec=N*LleakPri
RPri=50m
RSec=N*RPri
N=1

2 Soft-Start

Soft-start function is realized by ramping up the SLEW signal during turning-on the turning-off of the converter.

The plot shows that transformer (secondary current is reflected to the primary and shown as IL) current during the soft-start, steady-state and soft-stop phases.

The current protection valley is set at 600mA and the load current is 283mA. It is observed that when the transformer current is valley-limited, VOUT does not rise as fast as the SLEW signal. This proves that the valley current protection is working fine. VFB is the signal from the resistive divider at the output.

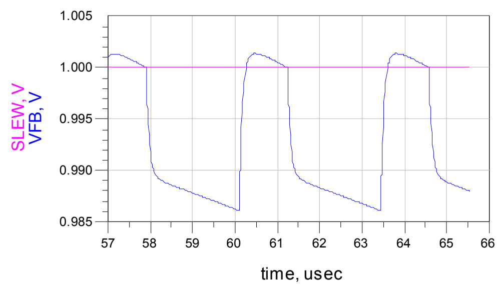


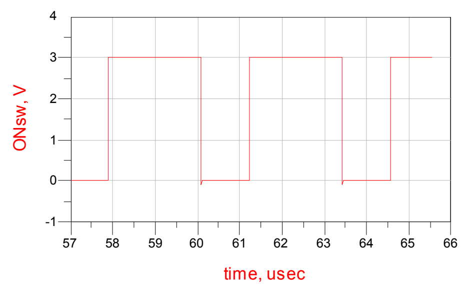
3 Steady-State

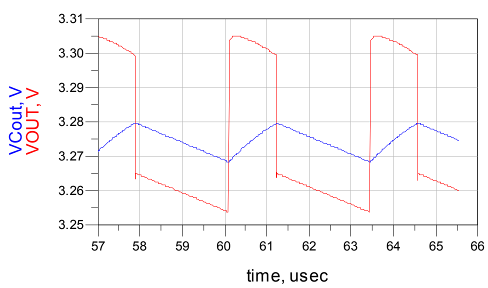
Some of the waveforms during steady state are shown for the case of battery voltage = 2V, 4V and 6V. The VOUT is set to be 3.3V. As the secondary current are zero during Ton, this requires a large output capacitor to ensure that the output voltage ripple is low. The output voltage ripple is mainly limited by the ESR of the output capacitor (Cout).

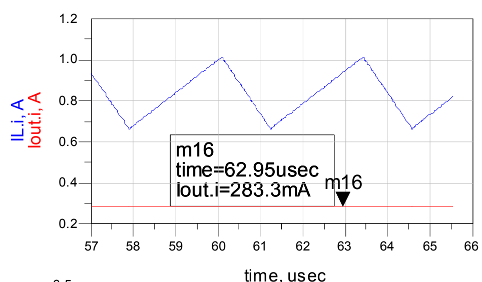
The results show that the output voltage ripples are 1.562%, 1.1% and 0.956% when battery voltage equals 2V, 4V and 6V respectively.

The ESR of Cout has the effect of creating a zero and helps to stabilize the feedback loop. High ESR results in higher ripple voltage but the system is more stable.

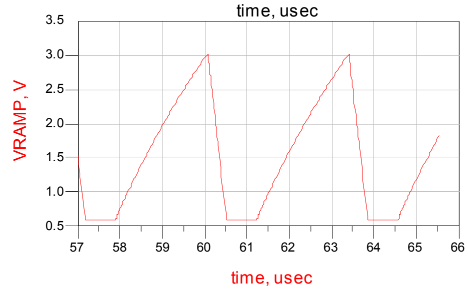


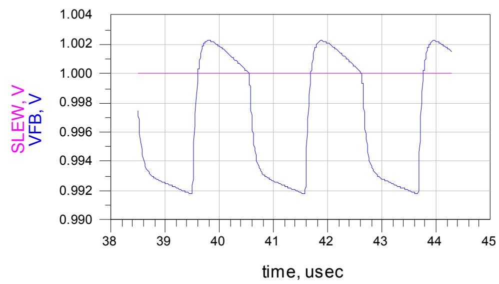


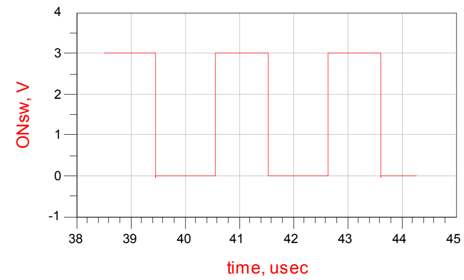


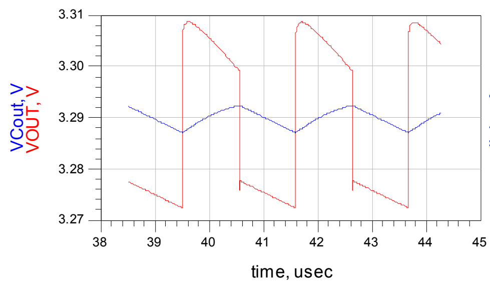


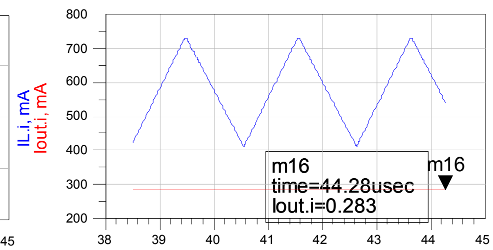
VIN	Vripple
2.000 V	1.562



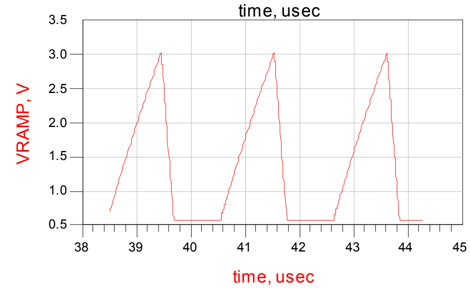


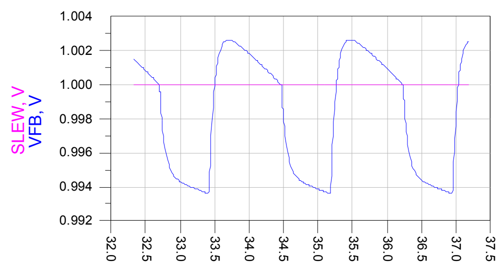


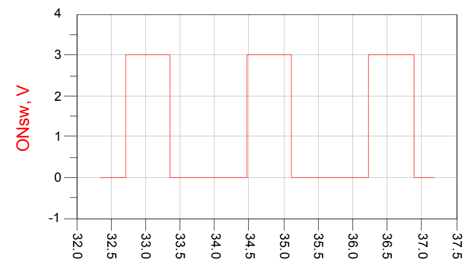


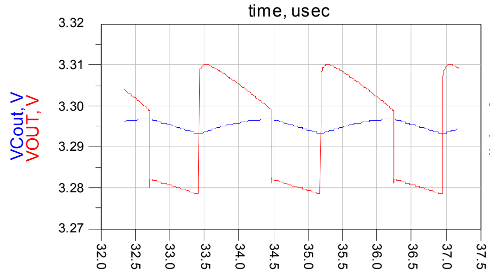


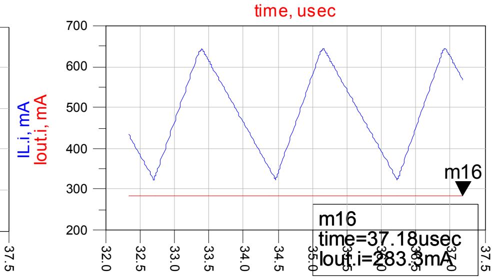
VIN	Vripple
4.000 V	1.100



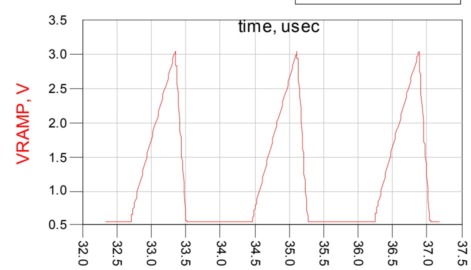








VIN	Vripple
6.000 V	0.956

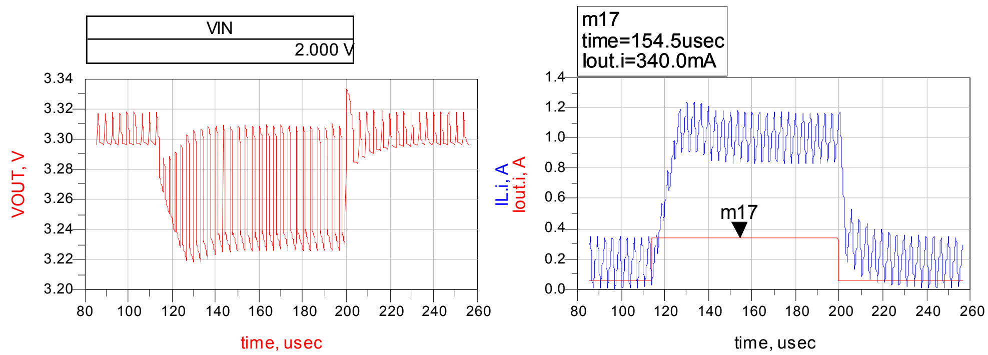


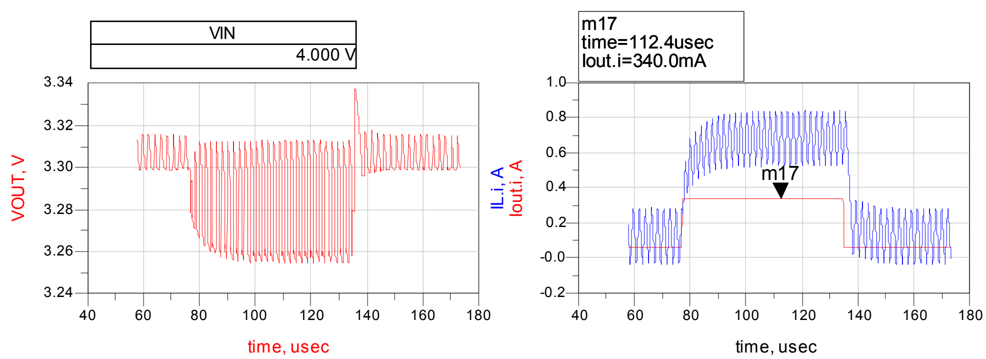
4 Load Transient

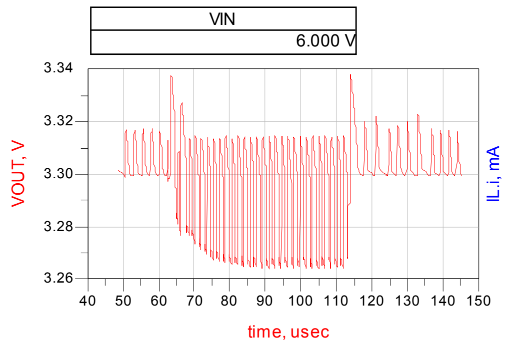
The load is varied from 20% to 120% of expected load current. The expected load current is 85% of 1.1W/3.3V.

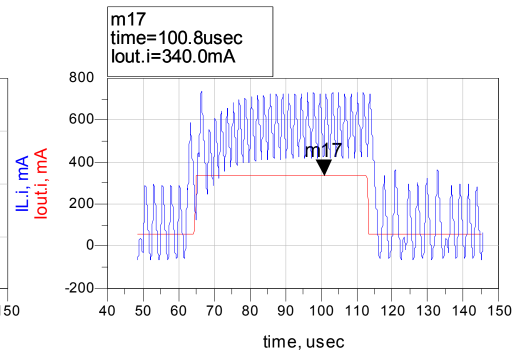
VOUT transient for battery voltage of 2V, 4V and 6V are shown.

The response the system to the load variation is very fast and the response time is in the order of few cycles of switching.






VIN
6.000 V
VOUT, V
time, usec


m17
time=100.8usec
Iout.i=340.0mA
IL.i, mA
Iout.i, mA
time, usec

5 Conclusion

The constant-Ton scheme of Little John can be used for flyback controller with the following modification:

1. No SKIP-mode is required.
2. Valley current protection is implemented in the secondary of the transformer.

The following areas have to be further explored:

1. Stability analysis of the system has to be fully understood. Current understanding is that the ESR of Cout (left-hand plane zero) helps to stabilize the system. However, there is no analytical equation to provide understanding of the effect. Furthermore, there is a RHP (right-hand plane zero) for flyback converter that will further complicate the stability issue. Buck converter (Little John) does not have the RHP zero issue.
2. Efficiency of flyback converter's is strongly depends on the type of transformer used, switching frequency, peak current allowed and etc. A suitable flyback transformer has to be selected. The model of the transformer has to be available for simulation in order to set the optimal operating parameter for best efficiency.
3. Leakage inductance of the transformer will create voltage spike and ringing in the circuit. The effect has to be taken care of and snubber circuit designed for it if necessary. The voltage spike and noise will affect the voltage and current sensing accuracy and hence affect the operation.
4. Understanding of cross-regulation of multiple-output flyback converter has to be acquired.